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Human Systems Integration Model Analyses in Support of the Joint Service Transportable Decontamination System – Small-Scale Increment I Acquisition Program

by Lamar Garrett and Asisat Animashaun

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14. ABSTRACT
In support of the Joint Program Executive Office for Chemical and Biological Defense, U.S. Army Research Laboratory researchers conducted human systems integration (HSI) for the Joint Service Transportable Decontamination System – Small-Scale (JSTD-SS) Increment I that incorporated a Manpower and Personnel Integration (MANPRINT) Assessment and Improved Performance Research Integration Tool models that simulated operator and maintainer workload. The MANPRINT assessment identified no critical issues, one major issue, and several minor issues using the seven domains of MANPRINT. The overall rating of the JSTDS-SS Increment I system was Amber. Based on the acquisition approach and data sources available, there are no issues or groups of HSI issues that preclude transitioning to the next phase of the material acquisition life cycle.

15. SUBJECT TERMS
JSTDS-SS, MANPRINT, IMPRINT, modeling, workload, equipment, decontamination, human factors

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1. Introduction

Existing decontamination assets consist of poorly maintained systems (M17 Senator Lightweight Decontamination System [M17 SLDS]) that require excessive maintenance and are no longer supportable due to a lack of production bases. These deficiencies have been the subject of a U.S. Central Command Operational Needs Statement prior to Operation Iraqi Freedom and subsequent Southern Region Operational Center, U.S. Southern Command actions. The U.S. Army and Marine Corps initially rectified existing capability shortfalls by fielding hundreds of nonstandard decontamination systems. In order to conduct decontamination operations, the Joint Program Executive Office for Chemical and Biological Defense (JPEOCBD) emphasizes the need for a standardized, lightweight, and transportable decontamination system.

Historically, decontamination assets present a huge technological challenge within the research and development community for chemical, biological, radiological, and nuclear (CBRN) defense. Currently, the armed services employ the same technology introduced over a half century ago. This includes decontaminants in use today, such as high-test hypochlorite, super-tropical bleach, and Decontamination Solution 2, which is caustic. These decontaminants can potentially damage equipment, pollute the environment, and cause personal injury as a result. Most of these decontaminants are flammable, very corrosive, and impractical for use on ships, high-performance aircraft, and non-hardened equipment. Therefore, future decontamination programs aim to reduce the logistical burden of transporting decontamination equipment and to develop more environmentally friendly decontaminant agents. The Joint Program Executive Office for the Family of Decontamination System has taken an innovative approach to field commercially available systems that are transportable by a platform in close proximity to combat operations and will be used to decontaminate tactical vehicles, shipboard surfaces, and crew-served weapons. The Joint Service Transportable Decontamination System – Small-Scale (JSTDS-SS) Increment I will provide joint, standardized, and fully supported decontamination capabilities necessary to enhance and preserve long-term readiness.

The JSTDS-SS Increment I is a commercial, off-the-shelf system that was developed using an incremental approach. The Increment I system provides improved capabilities over the current legacy system (M17 SLDS) to decontaminate tactical and non-tactical vehicles, ship exterior surfaces, crew-served weapons, aircraft, aircraft support equipment, building/facility exteriors, and terrain. The JSTDS-SS Increment I will be employed within the integrated battle space as a means to decontaminate CBRN and/or toxic industrial material hazards posing threats to military operations. Increment I of the JSTDS-SS addresses various types of agents, such as Nerve-G, Nerve-V, Blister-H, and radioactive contamination hazards. Increment II will focus on improving overarching decontamination processes, efficacy, and system capabilities for decontamination operations.

The JSTDS-SS Increment I will be fielded to replace the (M17 SLDS) to prevent a gap in Warfighter capability. This will provide an improved capability to the Warfighter, minimize the logistics footprint associated with the JSTDS-SS Increment I, and implement a cost-effective sustainment strategy using a performance-based logistics approach.

The JSTDS-SS Increment I will be used for thorough decontamination of non-sensitive military materiel, limited facility decontamination at logistics bases, airfields, naval ships, ports, command and control centers, and other fixed facilities. These systems may also support other hazard abatement missions as necessary. The intent of the JSTDS-SS Increment I system is to minimize logistic movement impact on strategic and intra-theater lift resources, minimize the manpower requirements, and maximize the use of robotics and automation. The structure of the Operational Requirements Document (ORD) was established to allow the program the flexibility to accelerate fielding of capability enhancements using commercial products for rapid deployment.

For the JSTDS-SS Increment I to enhance the Department of Defense (DOD) decontamination capability, the JPEOCBD had to ensure that personnel readiness was not compromised by equipment that was difficult to use or maintain. This entailed the use of the Army Manpower Personnel Integration (MANPRINT) Program. The MANPRINT program (http://www.manprint.army.mil/), covered under Army Regulation 602-2 (*1*), ensures that Soldier performance is a central consideration in system design, development, and the acquisition process. It is the technical process of integrating the interdependent elements (domains) of human factors engineering (HFE), manpower availability, personnel skills and abilities, training design, system safety, health hazards, and survivability. However, the focus of this effort centered on five of the seven MANPRINT domains, which included human factors engineering; manpower, personnel, and training (MPT); and Soldier survivability. The results obtained from the assessments and analyses were used to assist the JPEOCBD with system design recommendations and optimize human-system performance.

2. Objectives

The objective of this project was to conduct a MANPRINT assessment for the JSTDS-SS Increment I. As part of the MANPRINT assessment, a combined manpower, personnel, and training assessment (MPTA), human factors engineering assessment (HFEA), and Soldier survivability assessment (SSvA) for the JSTDS-SS Increment I program was conducted.

3. Methodology

3.1 MANPRINT Assessment

MANPRINT is a comprehensive management and technical program that focuses on the integration of human considerations (i.e., capabilities and limitations) into the system acquisition process: concept development, test and evaluation, documentation, design, development, fielding, post-fielding, operation, and modernization of systems. MANPRINT is used to enhance Soldier-system design, reduce life-cycle ownership costs, and optimize total system performance. This is achieved by ensuring the human is fully and continuously considered as part of the total system (i.e., hardware and software) in the development and/or acquisition of all systems. Human performance is a key factor in total system performance, and enhancements to human performance will correlate directly to enhanced total system performance and reduce life-cycle costs.

For the JSTDS-SS, ARL conducted a MANPRINT assessment utilizing various assessment techniques that included evaluating manpower, personnel, training, human factors engineering, and Soldier survivability based on data and documentation available. The assessment sought to capture an issue, problem, or concern that could impact one or more domains, with each issue listed under the domain for which it had the greatest impact. Each of these MANPRINT domains is described in greater detail in the following paragraphs.

Issues, problems, or concerns are defined as follows:

1. A critical issue is a system characteristic, which if not remedied, could reasonably be expected to result in death or serious bodily injury, mission abort, loss of the system, inability of the system to perform its intended mission, or an unacceptable impact on the manpower, personnel, or training requirements of the system.

2. A major issue is a system characteristic, which if not remedied, could reasonably be expected to result in bodily injury, reduced mission performance, extensive system damage, seriously diminished capacity of the system to perform its intended mission, or a significant negative impact on the manpower, personnel, or training requirements of the system.

3. A minor issue, problem, or concern is a system characteristic which, if not remedied, could reasonably be expected to result in discomfort of the Soldier, reduced mission effectiveness, system damage, diminished capacity of the system to perform its intended mission, or negative impact on the MANPRINT requirements of the system.

3.2 Manpower, Personnel, and Training Assessment

An MPTA is an evaluation of MPT risks associated with a system. Manpower refers to the number of people required to operate, maintain, support, and provide training for a system. Personnel refers to the human aptitudes, skills, knowledge, and experience required to perform as an operator or maintainer. Training refers to the instruction or education and on-the-job or unit training required to provide the workforce with requisite job skills, knowledge, and aptitudes to operate and maintain the system. An MPTA addresses the impact the system will have on MPT resource requirements and provides information for the use of these MANPRINT elements to help minimize overall life-cycle costs.

The approach used to develop data to inform the MPTA was to conduct an improved performance research integration tool (IMPRINT) analysis (http://www.arl.army.mil/IMPRINT). IMPRINT is a stochastic task-network modeling tool designed to help assess the interaction of Soldier and system performance from concept and design through field testing and system improvement. This analysis used two IMPRINT modules (operations and maintenance) to determine operator-system feasibility by predicting the impact of design changes on system performance. Operations module analysis estimated mental task demands and determined optimal crew size using the visual, auditory, cognitive, and psychomotor (VACP) workload scales that describe the four processing components of mental workload (*2*). Maintenance model analysis examined maintenance procedures and performance under extreme conditions by assessing the feasibility of combining various crew/organization- level maintenance tasks, evaluating manpower requirements from failure rates of individual components, and predicting the total number of service personnel required by Military Occupational Specialty (MOS) to meet system availability requirements. The IMPRINT maintenance model acronym list is found in appendix A.

3.3 Human Factors Engineering Assessment

An HFEA is a review of the status of the HFE processes and accomplishments within system development as it approaches the end of each life-cycle phase. Its purpose is to influence and support the milestone decision review process that determines whether the system is ready to transition to the next scheduled phase. Broad areas addressed by the HFEA are the HFE detailed design and Soldier performance considerations as they relate to the operation, maintenance, support, and the way these factors might impact the system's pre-established MPT goals and constraints. A major thrust of the HFEA is to identify man-machine interface issues which, taken individually or collectively, may be so objectionable that if not remedied, they would warrant a decision not to transition into the next phase. The HFEA will also identify existing problems or concerns not serious enough to preclude transitioning, which should be resolved to enhance total system operational effectiveness. The HFEA approach involved a task analysis of user interaction and a risk analysis to identify possible system problems.

3.4 Soldier Survivability Assessment

The SSvA documents a review of the status of the system's ability to reduce the Soldier's ability to detect, prevent attack if detected, prevent damage if attacked, minimize medical injury if wounded, reduce mental and physical fatigue, and reduce fratricide. This assessment identifies problems or concerns that should be resolved to enhance total system effectiveness.

4. Analysis

4.1 Manpower, Personnel, and Training Assessment: IMPRINT Analysis

The VACP modeling method was utilized for the development of the JSTDS-SS operator workload analysis. The VACP workload scales provide a rating of the degree to which an individual resource is utilized for each task. Completing a task requires utilization of at least one resource and typically requires the simultaneous use of multiple resources. Each task resource requirement was rated on the VACP scale (see table 1) (*2*). The four resource channel scales range from 0.0 to 7.0. A threshold score of 7 represents 100% capacity for that individual resource channel and is indicative of maximum capacity. IMPRINT calculates the overall workload value for that time by summing all of the values for each resource for each task. The maximum total combined overall workload value for a single task is 28 (V + A + C + P). This represents the maximum combined workload of all four resource channels. Preliminary model runs revealed low overall workload measures due to task simplicity, and therefore an overall overload value of 28 was used as the overload threshold. Multiple tasks occurring simultaneously may result in a resource channel value greater than 28. Therefore, when workload values exceeded the threshold limits, the operator was considered to have a mental overload. Operator model input data are shown in table 2.

Table 1. VACP values and descriptors.

Scale Value	Scale Descriptor
Visual	
0.0	No visual activity
1.0	Visually register/detect (detect occurrence of image)
3.7	Visually discriminate (detect visual differences)
4.0	Visually inspect/check (discrete inspection/static condition)
5.0	Visually locate/align (selective orientation)
5.4	Visually track/follow (maintain orientation)
5.9	Visually read (symbol)
7.0	Visually scan/search/monitor (continuous/serial inspection, multiple conditions)
Auditory	
0.0	No auditory activity
1.0	Detect/register sound (detect occurrence of sound)
2.0	Orient to sound (general orientation/attention)
4.2	Orient to sound (selective orientation/attention)
4.3	Verify auditory feedback (detect occurrence of anticipated sound)
4.9	Interpret semantic content (speech)
6.6	Discriminate sound characteristics (detect auditory differences)
7.0	Interpret sound patterns (pulse rates, etc.)
Cognitive	
0.0	No cognitive activity
1.0	Automatic (simple association)
3.7	Sign/signal recognition
4.6	Evaluation/judgment (consider single aspect)
5.3	Encoding/decoding, recall
6.8	Evaluation/judgment (consider several aspects)
7.0	Estimation, calculation, conversion
Psychomotor	
0.0	No psychomotor activity
1.0	Speech
2.2	Discrete actuation (button, toggle, trigger)
2.6	Continuous adjustive (flight control, sensor)
4.6	Manipulative
5.8	Discrete adjustive (rotary, vertical thumbwheel, lever position)
6.5	Symbolic production (writing)
7.0	Serial discrete manipulation (keyboard entries)

Table 2. Operator model required model input data (*3–7*).

Independent Variables	Dependent Variables
•Task allocation •Number of operators •MOPP (with MOPP, without MOPP)	•Time to complete mission •Visual workload •Auditory workload •Cognitive workload •Psychomotor workload •Overall workload

The model scenario was based on a functional decomposition of system elements during a nuclear, biological, and chemical (NBC) decontamination operation using procedures found in FM 3-11.5 (*5*). The system is broken down into four main functions: equipment setup, vehicle preparation, start engine, and vehicle wash down. (See appendix B for a diagram of the breakdown). Within these functions are subtasks that describe the decontamination operation procedures.

To construct the model, the analyst was required to make assumptions based on information provided by subject matter experts (SMEs), information from FM 3-11.5 (*5*), and the JSTDS-SS operations manual (*3*). SMEs were JSTDS-SS operators with 20 years of military operational experience in the field of NBC decontamination.

- Two JSTDS-SS systems were used for the dual-operator model, with one assigned to each operator, whereas for the single-operator model, one JSTDS-SS system was used.
- The JSTDS-SS systems were unloaded from the vehicle prior to mission start.
- The operator interacts with the following controls: hearing protection, spray lance, JSTDS-SS, and vehicles requiring decontamination.

The model scenario was based on information received from discussion with SMEs. The workload model consisted of a worst-case decontamination operation of a 14-tank company. The scenario captures the mental workload of the tasks operators repeat throughout the decontamination mission. A baseline model with a single operator conducting all procedural decontamination tasks and a dual-operator model with tasks distributed between the two operators were developed in IMPRINT.

Additional models were run with the MOPP ensemble performance moderator in IMPRINT applied to the single- and dual-operator model conditions to determine the degradation effects of the MOPP ensemble on performance. The model was run 10 times for the single- and dual-operator conditions. Data on task time, workload, and overload were collected and an analysis performed. The overall workload threshold was set to 28, and the individual resource channel thresholds (visual, auditory, cognitive, and psychomotor) limits were set to 7 (*7*). Any instances of high workload are due to the combination of tasks occurring at one time.

4.1.1 Single-Operator Decontamination

In the baseline single-operator decontamination model, a single Soldier is responsible for conducting decontamination procedures for a tank company. The overall workload of the operator, excluding MOPP ensemble, is depicted in figure 1, and peak workload values and corresponding tasks are highlighted. The operator is not in overload at any point during the scenario. The operator experiences workload levels ranging from 3.2 to 15.4. Due to the low workload level and the repetitive nature of the task, the operator may be at risk for mental underload. Underload exists when low mental demands are present and can be as detrimental to performance as overload. A large majority of the tasks require physical exertion and visual inspection and therefore challenge the operator to utilize the visual and psychomotor resources together. A single mission without the MOPP is completed in just over 77 min, as shown in table 3.

Table 3. Single-operator (without MOPP) mission completion time.

Single Decontamination Operator Without MOPP	
—	hh:mm:ss:ms[a]
Mission completion time	01:17:33:00

[a] hours:minutes:seconds:milliseconds.

Figures 1 and 2 depict the workload levels for the overall workload during the single-operator decontamination mission without stressor and the individual resource channels. Peak workload values and corresponding tasks are highlighted. The visual, auditory, cognitive, and psychomotor resource channels do not exceed 7 and are never overloaded. Workload values greater than 7 for an individual resource or greater than 28 for the overall combined resources are considered high.

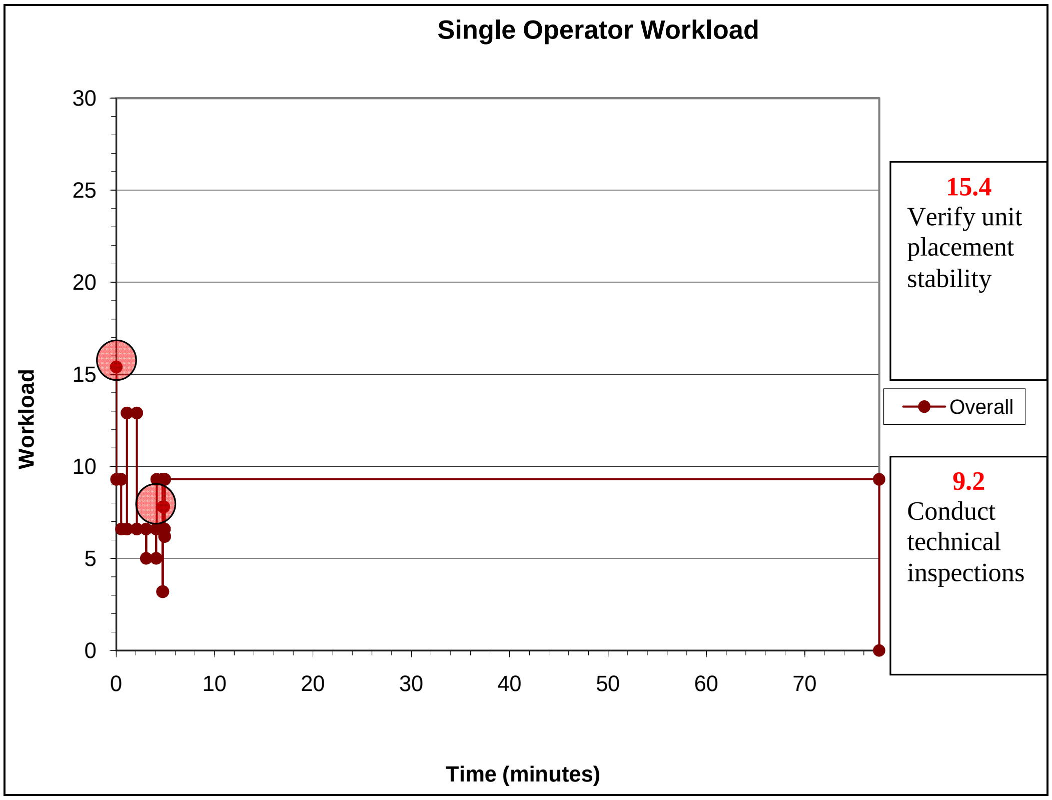

Figure 1. Overall single-operator workload without MOPP.

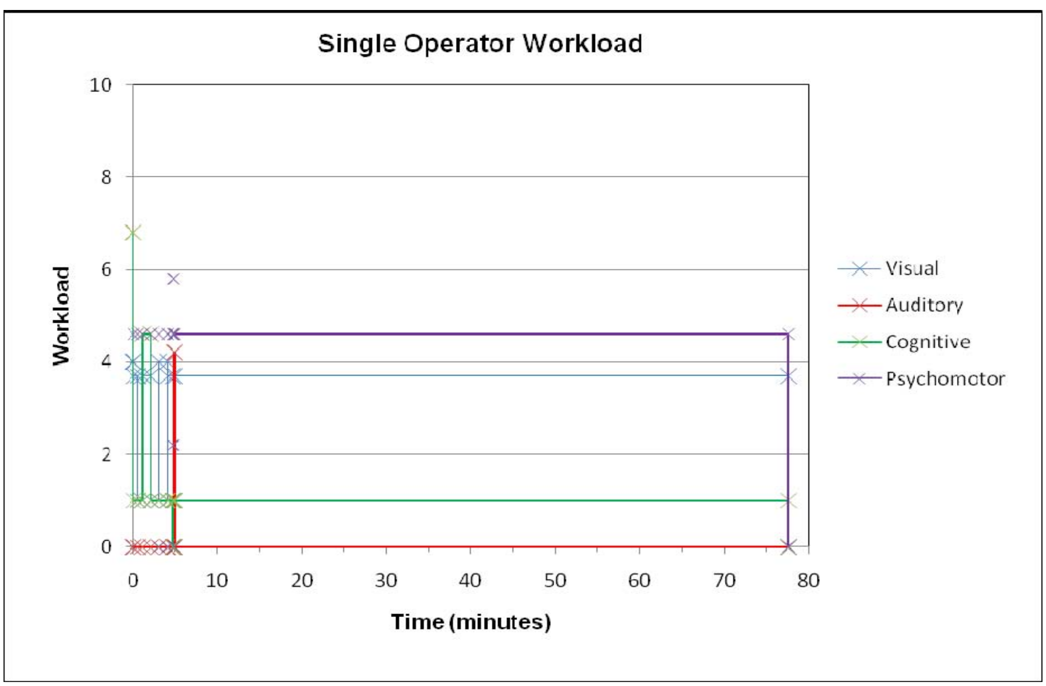

Figure 2. VACP single-operator workload without MOPP.

The single operator conducting decontamination operations with the added MOPP ensemble resulted in an increase in the overall mission completion time, as shown in table 4. The overall mission time increased by nearly an hour with the MOPP ensemble, but there was no operator overload. The overall workload of the operator, including MOPP ensemble, is depicted in figure 3. The operator is not in overload at any point during the scenario, and the overall workload never exceeds the workload threshold of 28. The operator experiences workload levels from 3.2 to 15.4.

Table 4. Single-operator (with MOPP) mission completion time.

Single-Scout Decontamination With MOPP	
—	hh:mm:ss:ms[a]
Mission completion time	02:04:26:07

[a] hours:minutes:seconds:milliseconds.

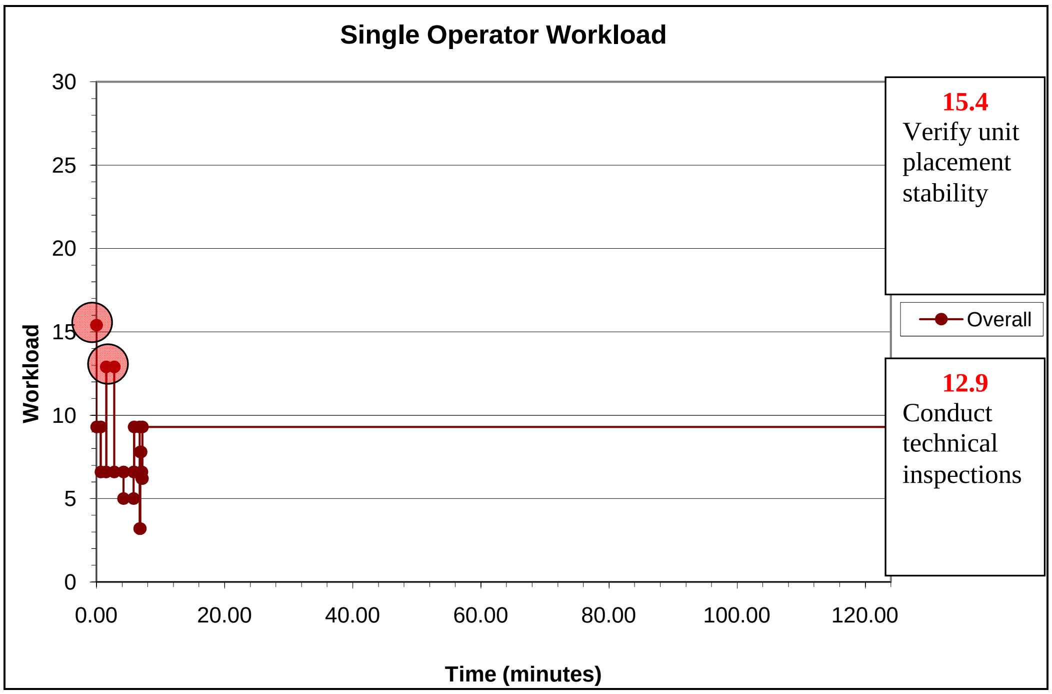

Figure 3. Overall single-operator workload with MOPP.

Figure 4 depicts the workload levels for the individual resource channels during the single-operator decontamination mission with MOPP gear. Peak workload values and corresponding tasks are highlighted. The visual, auditory, cognitive, and psychomotor resource channels do not exceed 7 and are never overloaded. Workload values greater than 7 for an individual resource or greater than 28 for the overall combined resources are considered high.

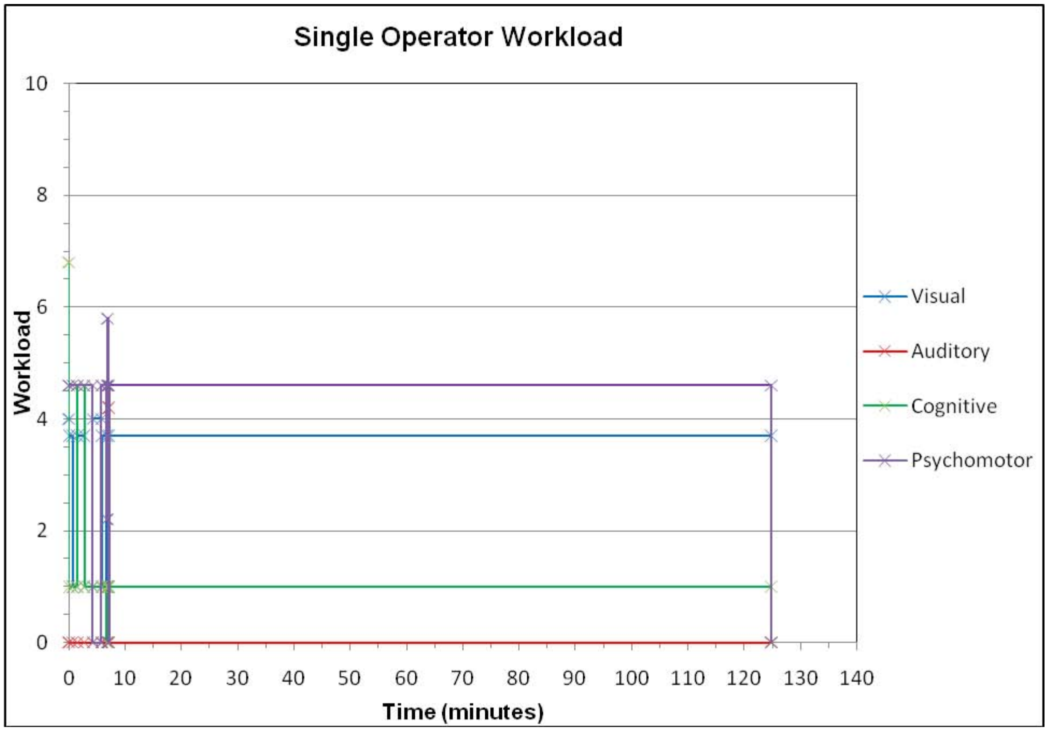

Figure 4. VACP single-operator workload with MOPP.

4.1.2 Dual-Operator Decontamination

With two operators using a single decontamination system, there was a reduction in the overall time to complete the mission. The mission was completed nearly 40 min faster than the single-operator completion time, as shown in table 5. Workload values generally remained the same as the single operator. Differences between workload values of the operators of the single- and dual-operated systems were due to the task assignments between operators.

Table 5. Dual-operator (without MOPP) mission completion time.

Dual-Scout Decontamination Without MOPP	
—	hh:mm:ss:ms[a]
Mission completion time	00:38:32:40

[a] hours:minutes:seconds:milliseconds.

The overall workload of the operator without MOPP ensemble is depicted in figures 5 and 6. The workload levels off for the individual resource channels and overall during the dual-operator decontamination mission without stressor. Peak workload values and corresponding tasks are highlighted. The visual, auditory, cognitive, and psychomotor resource channels do not exceed 7 and are never overloaded. Workload values greater than 7 for an individual resource or greater than 28 for the overall combined resources are considered high.

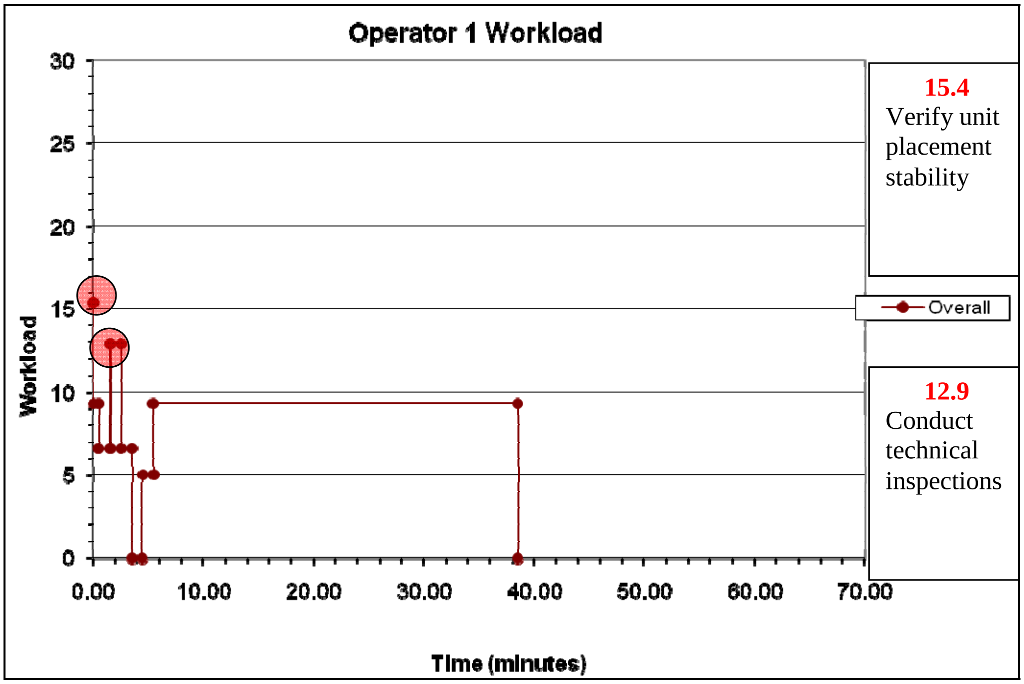

Figure 5. Operator 1 overall workload without MOPP.

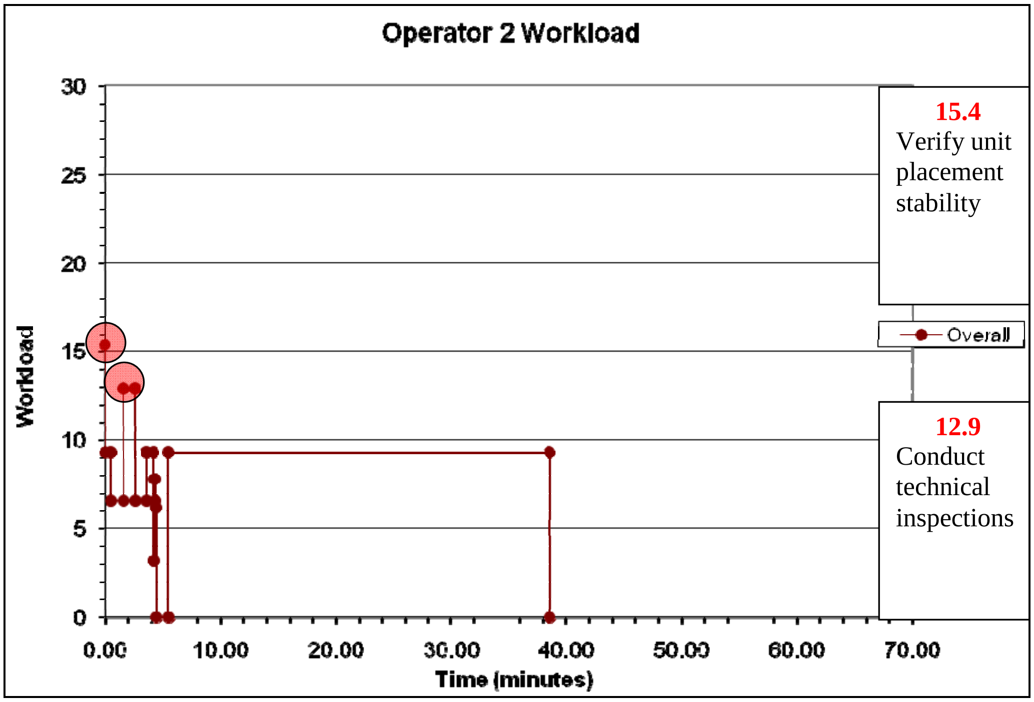

Figure 6. Operator 2 overall workload without MOPP.

Figures 7 and 8 depict the workload levels for the individual resource channels during the dual-operator decontamination mission without MOPP gear. Peak workload values and corresponding tasks are highlighted. The visual, auditory, cognitive, and psychomotor resource channels do not exceed 7 and are never overloaded. Workload values greater than 7 for an individual resource or greater than 28 for the overall combined resources are considered high.

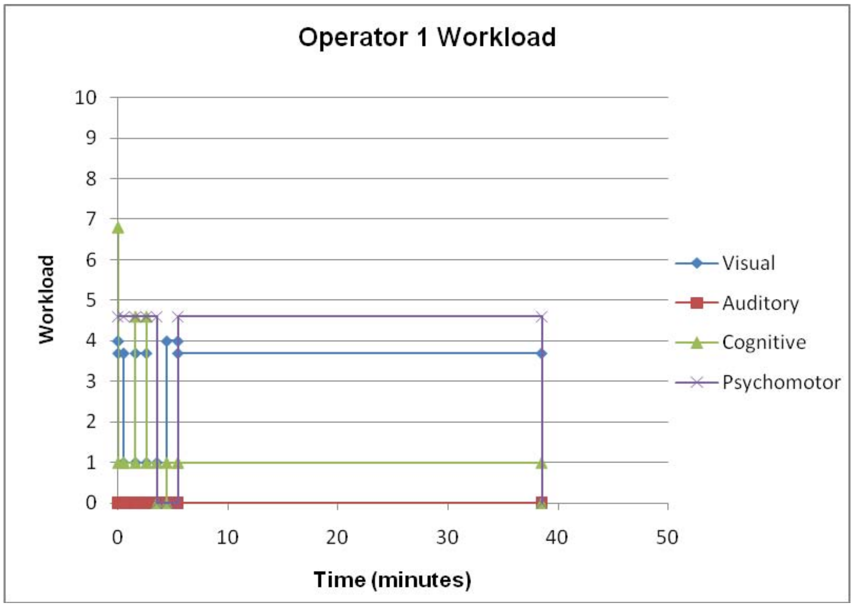

Figure 7. Operator 1 VACP workload without MOPP.

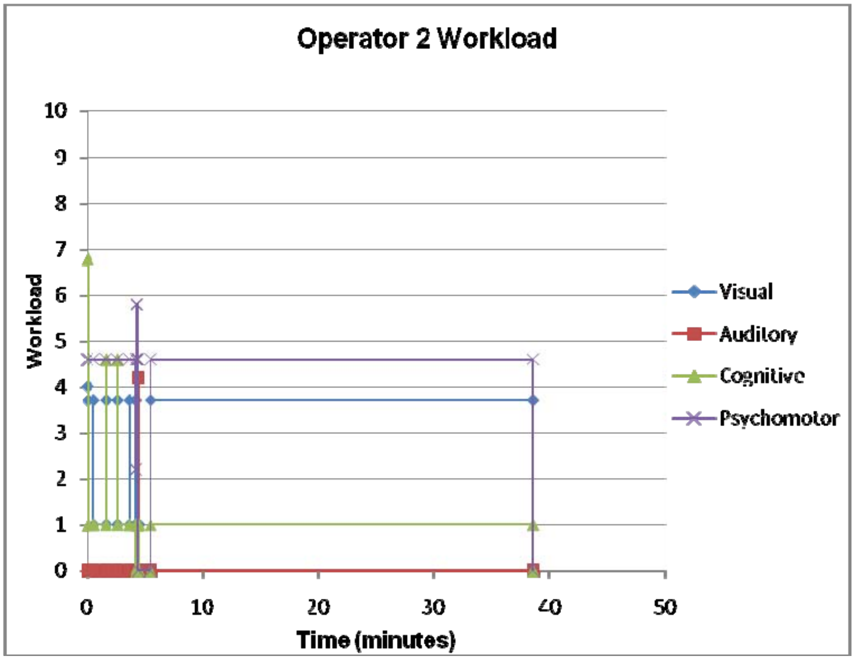

Figure 8. Operator 2 VACP workload without MOPP.

Two operators using a decontamination system while wearing MOPP ensemble compared to two operators with no MOPP ensemble resulted in the mission completion time increase of 23 min. However, when compared to a single operator with MOPP gear, the mission completion time decreased by 63 min. The mission was completed 16 min faster using dual operators with MOPP gear as opposed to using a single operator without MOPP gear, as shown in table 6.

Table 6. Dual-operator (with MOPP) mission completion time.

Dual-Scout Decontamination With MOPP	
—	hh:mm:ss:ms[a]
Mission completion time	01:01:25:32

[a] hours:minutes:seconds:milliseconds.

Figures 9 and 10 depict the overall workload levels for both operators during the dual-operator decontamination mission with MOPP gear. Peak workload values and corresponding tasks are highlighted. Workload values greater than 7 for an individual resource or greater than 28 for the overall combined resources are considered high. The overall peak workload value for the operators is 15.4. The visual, auditory, cognitive, and psychomotor resource channels do not exceed 7; therefore, the operators are not overloaded.

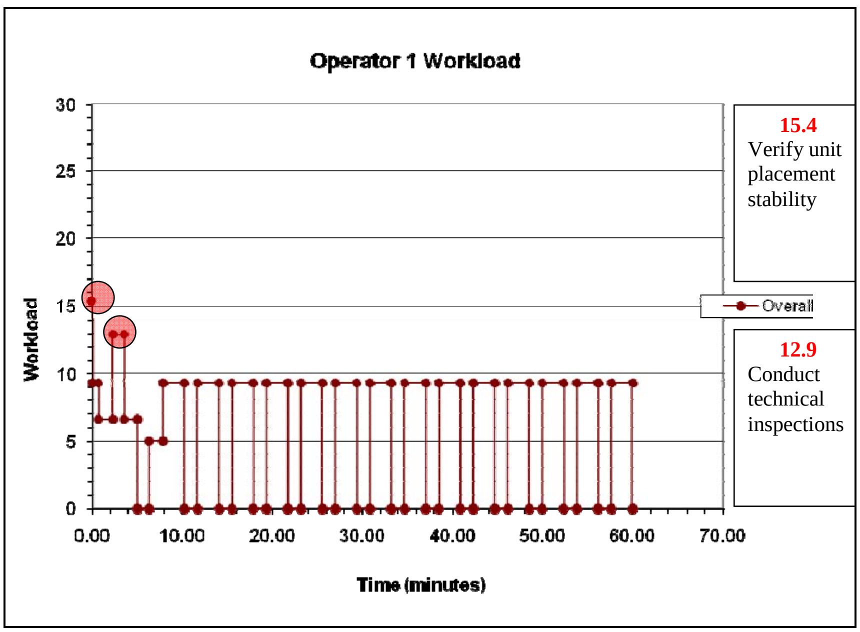

Figure 9. Operator 1 overall workload with MOPP.

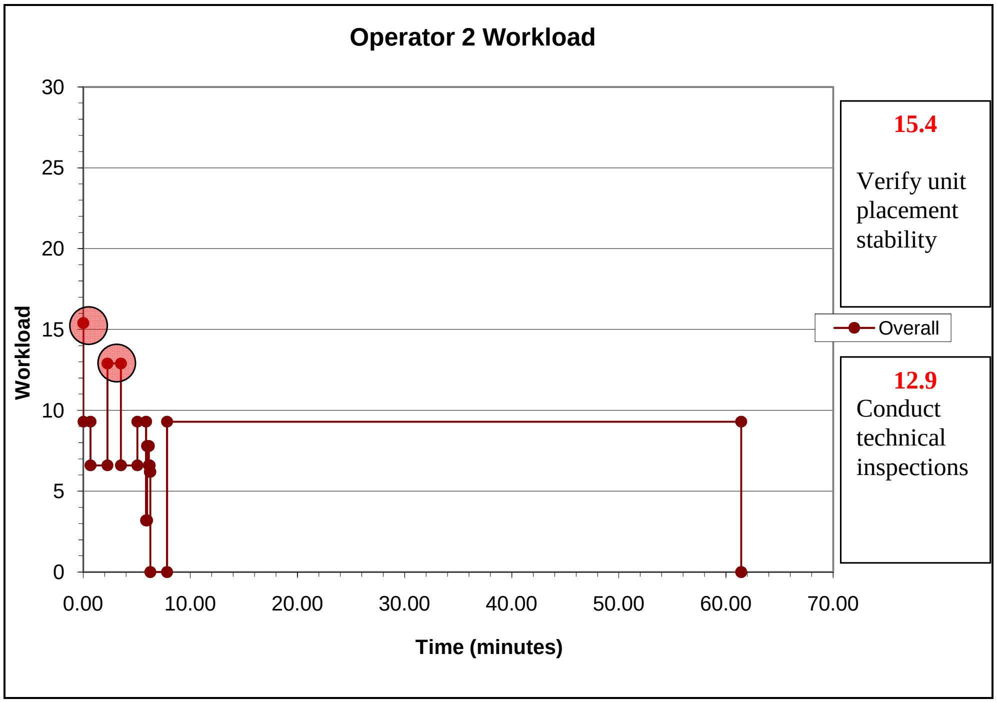

Figure 10. Operator 2 overall workload with MOPP.

Figures 11 and 12 depict the workload levels for the individual resource channels during the dual-operator decontamination mission with MOPP gear. Peak workload values and corresponding tasks are highlighted. The visual, auditory, cognitive, and psychomotor resource channels do not exceed 7 and are never overloaded. Workload values greater than 7 for an individual resource or greater than 28 for the overall combined resources are considered high.

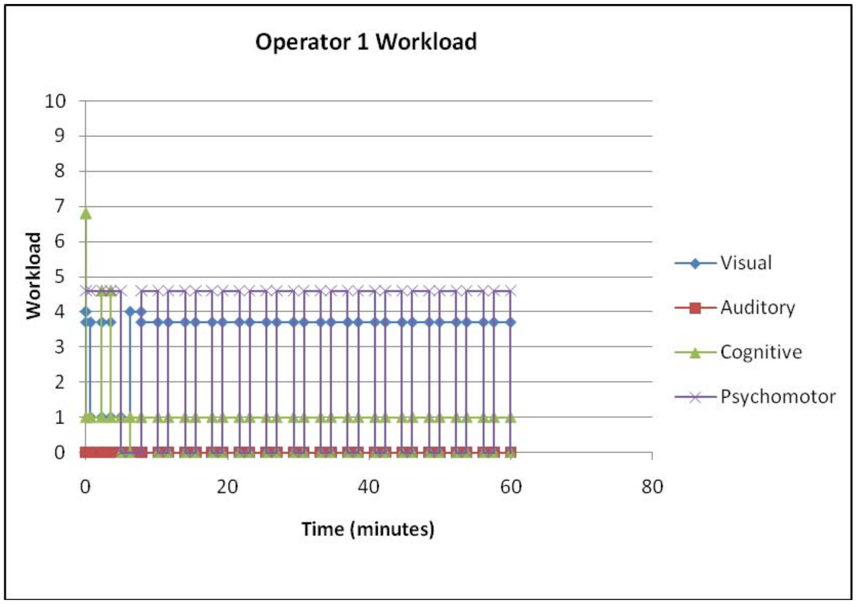

Figure 11. Operator 1 VACP workload with MOPP.

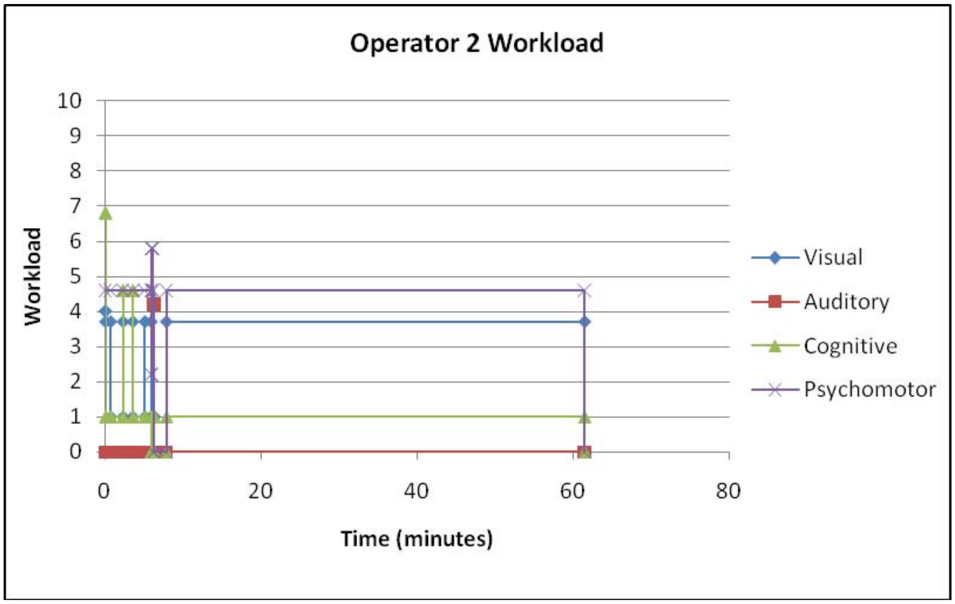

Figure 12. Operator 2 VACP workload with MOPP.

The operator was not in overload at any point during both the single- and dual-operator decontamination missions, and workload levels remained the same. Mission lengths increased for both the single- and dual-operator missions with the added MOPP ensemble. Operator workload levels remained similar throughout all of the modeled scenarios.

4.2 JSTDS-SS Increment I Maintenance Model

The model uses the functional breakdown of a system from the upper level to the lower levels (i.e., system, subsystem, components). Most manufacturers use some form of system engineering development process to describe how the system is designed, manufactured, and assembled. This lends itself nicely to describing the various parts that compose the overall product.

IMPRINT assumes that the reliability of a system's components can be modeled according to the behavior of the negative exponential distribution function. Assuming this is the case, the mean operational units between failure (MOUBF) is the inverse of the failure rate or task frequency. In addition, the model assumes that series reliability is the algorithm used to calculate the overall reliability for the system (see appendix C). Additionally, model runs were conducted with and without the use of stressors. These stressors simulate the performance degradation effects that result when extra burdens are placed on the human. Included in the analyses were the effects of cold, wind, MOPP ensemble, and sleep deprivation for 72 h of sustainment operations. Unfortunately, the stressor effects from heat, humidity, and noise could not be evaluated at this time due to a technical problem with the model. Required model input data are shown in table 7.

Table 7. Required model input data (*3, 8–10*).

Subsystem	Scenario
•Name •Equipment type	•Shift manning •Travel time •Number of systems •Length
Repair Task	**Mission Segment**
•MOUBF •Mean time to repair (MTTR) •MTTR standard deviation •MTTR distribution •MOS + (number of MOS) •Organization level •Contact team •Percent abort	•Start time •Start day •Cancellation time •Duration •Priority •Minimum number of systems •Maximum number of systems •Number/departure groups •Consumables •Combat damage

Input data for the model pertaining to subsystems, components, task action, maintenance type corrective/preventive, organizational level, and mean operational units between maintenance (MOUBM) for preventive maintenance tasks were obtained from the operation and maintenance manual for the MPDS-JSTDS (*3*). Input data for the MTTR for both preventive and corrective maintenance tasks and the MTBF for corrective tasks were obtained from SMEs. Input data pertaining to the operational scenario were obtained from the ORD for the system and the Engineering Design Test (EDT) for the JSTDS-SS (*10*).

Based on discussions with SMEs, it was decided to model 12 systems per company. An operational scenario of 10 h/day was modeled for 1 year to examine the worst case scenario. Table 8 lists the most critical IMPRINT maintenance model input data, as described previously.

Table 8. Critical IMPRINT maintenance model input data.

Subsystem	Component	Main Type	Org	MOS	MOUBF (h)	MTTR (hh:mm:ss.ms)[a]
JSTDS	Manometer pump pressure	Corrective	Org	63J	100000.00	00:10:00.00
JSTDS	Water safety valve	Corrective	Org	63J	100000.00	00:20:00.00
JSTDS	Screen chemical suction hose	Preventive	Org	63J	40.00	00:05:00.00
JSTDS	Screen chemical suction hose	Corrective	Org	63J	100000.00	00:20:00.00
JSTDS	Line filter	Preventive	Org	63J	40.00	00:05:00.00
JSTDS	Water pump	Preventive	Org	63J	40.00	00:05:00.00
JSTDS	Water pump	Corrective	Org	63J	150000.00	00:60:00.00
JSTDS	Battery	Corrective	Org	63J	100000.00	00:15:00.00
JSTDS	Throttle lever	Corrective	Org	63J	150000.00	00:20:00.00
JSTDS	Fuel suction tube w/canister	Corrective	Org	63J	200000.00	00:15:00.00
JSTDS	Water outlet	Corrective	Org	63J	500000.00	00:20:00.00
JSTDS	Exhaust hose – diesel motor	Corrective	Org	63J	300000.00	00:30:00.00
JSTDS	Pressure switch	Corrective	Org	63J	350000.00	00:10:00.00
JSTDS	Emergency shutdown valve	Corrective	Org	63J	500000.00	00:20:00.00
JSTDS	Metering calcium inhibitor/sol valve	Corrective	Org	63J	250000.00	00:20:00.00
Motor	Motor, change oil	Preventive	Org	63J	100.00	00:15:00.00
Motor	Valves	Preventive	Org	63J	100.00	00:35:00.00
Motor	Cooling fins	Preventive	Org	63J	100.00	00:10:00.00
Motor	Attachment bolts	Preventive	Org	63J	100.00	00:10:00.00
Motor	Motor, change oil and filter	Preventive	Org	63J	300.00	00:20:00.00
Motor	Motor, change oil and filter	Corrective	Org	63J	1000.00	00:05:00.00
Motor	Suction line/calcium stabilizer	Preventive	Org	63J	300.00	00:05:00.00
Motor	Fuel filter	Preventive	Org	63J	500.00	00:08:00.00
Motor	Motor diesel	Corrective	Org	63J	10000.00	00:60:00.00
Operator panel	Control lamp, charging indicator	Corrective	Org	63J	5000.00	00:10:00.00
Operator panel	Control lamp, magnetic clutch	Corrective	Org	63J	5000.00	00:10:00.00
Operator panel	Control lamp, burner switch	Corrective	Org	63J	5000.00	00:10:00.00
Operator panel	Control lamp, burner malfunction	Corrective	Org	63J	5000.00	00:10:00.00
Operator panel	Reset burner, malfunction	Corrective	Org	63J	50000.00	00:30:00.00
Operator panel	Operation hours counter	Corrective	Org	63J	300000.00	00:30:00.00
Operator panel	Thermostat w/temp indicator	Corrective	Org	63J	500000.00	00:45:00.00
Operator panel	Push button-motor oil preheat	Corrective	Org	63J	500000.00	00:20:00.00
Operator panel	Push button suction air motor preheat	Corrective	Org	63J	500000.00	00:20:00.00
Operator panel	Selector switch	Corrective	Org	63J	350000.00	00:45:00.00
Water pump	Valves	Preventive	Org	63J	500.00	00:20:00.00
Water pump	Water pump housing	Preventive	Org	63J	500.00	00:15:00.00
Water pump	Pulsation damper	Corrective	Org	63J	150000.00	00:10:00.00
Water pump	Pulsation damper	Preventive	Org	63J	500.00	00:05:00.00
Flow-through heater	Flow-through heater + burner nozz/ign	Preventive	Org	63J	500.00	00:20:00.00
Flow-through heater	Flow-through heater + burner nozz/ign elect	Corrective	Org	63J	600000.00	01:30:00.00
Electrical equipment	Electrical equipment	Preventive	Org	63J	500.00	00:20:00.00
Suction line/cal stab	Suction line/cal stab	Preventive	Org	63J	500.00	00:10:00.00

[a]hours:minutes:seconds.milliseconds.

Figure 13 shows the results of model runs with all stressors off, which could be thought of as a baseline condition. It should be noted that the subsystems with the highest number of maintenance man hours per system per year are the "motor" and "JSTDS." The motor subsystem requires 44.6 h/year of preventive maintenance based on the modeling conditions of 12 systems operated for 10 h/day for 1 year. The model assumed that one 63J operator/maintainer would perform the maintenance at the org level on the equipment, and no travel time was required to reach the system. In addition, it was assumed that all spare parts would be available when needed and therefore no wait time involved. The subsystem with the next highest level of preventive maintenance was the JSTDS at 19.9 h/year. Subsequent figures will describe the components that make up these subsystems and list their maintenance man hours (MMH). It should be noted that this figure, as well as most in this report with the exception of figure 19, shows preventive maintenance hours. This is because most of the corrective MOUBFs are very large and exceed the total operational hours for the 1-year simulation. On the other hand, all of the preventive MOUBFs, or more correctly MOUBMs in the case of preventive actions, are well within the 1 year of operation.

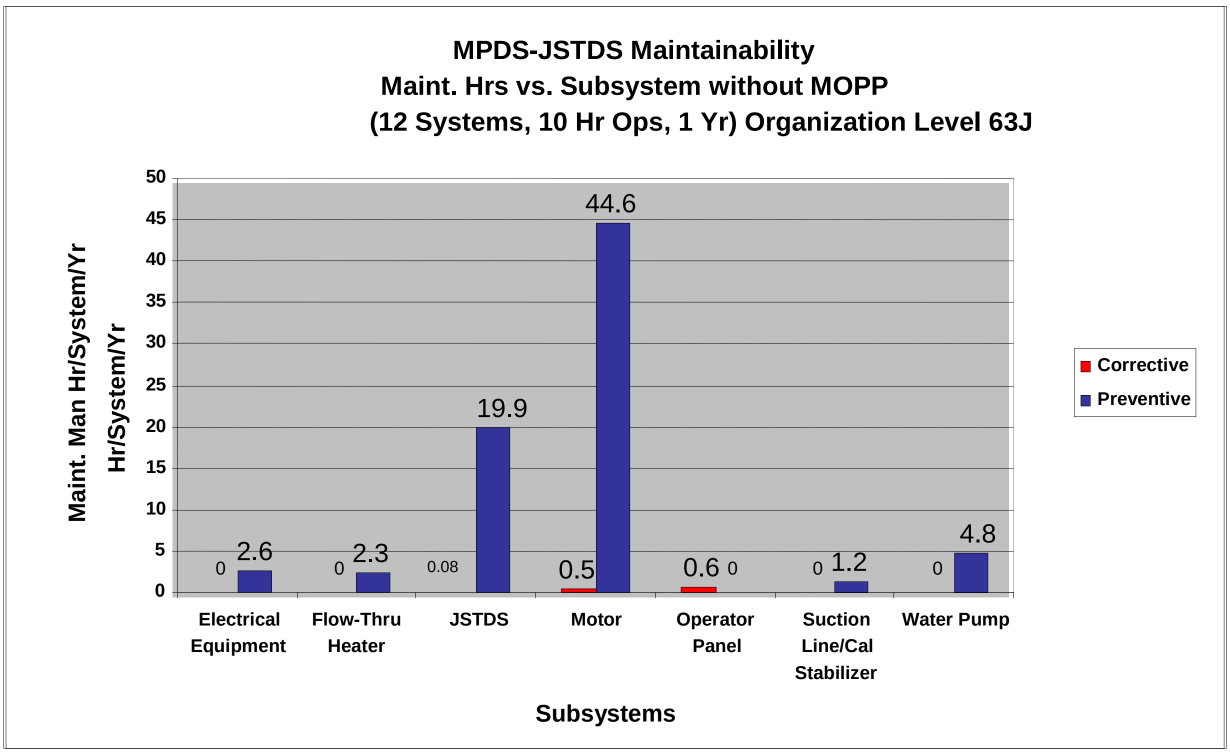

Figure 13. JSTDS-SS Increment I maintenance hours without MOPP.

Figure 14 depicts the same modeling conditions as figure 13 with the important addition of “Stressors On.” Included were the effects of cold, wind, MOPP IV, and sleep deprivation for 72 h.

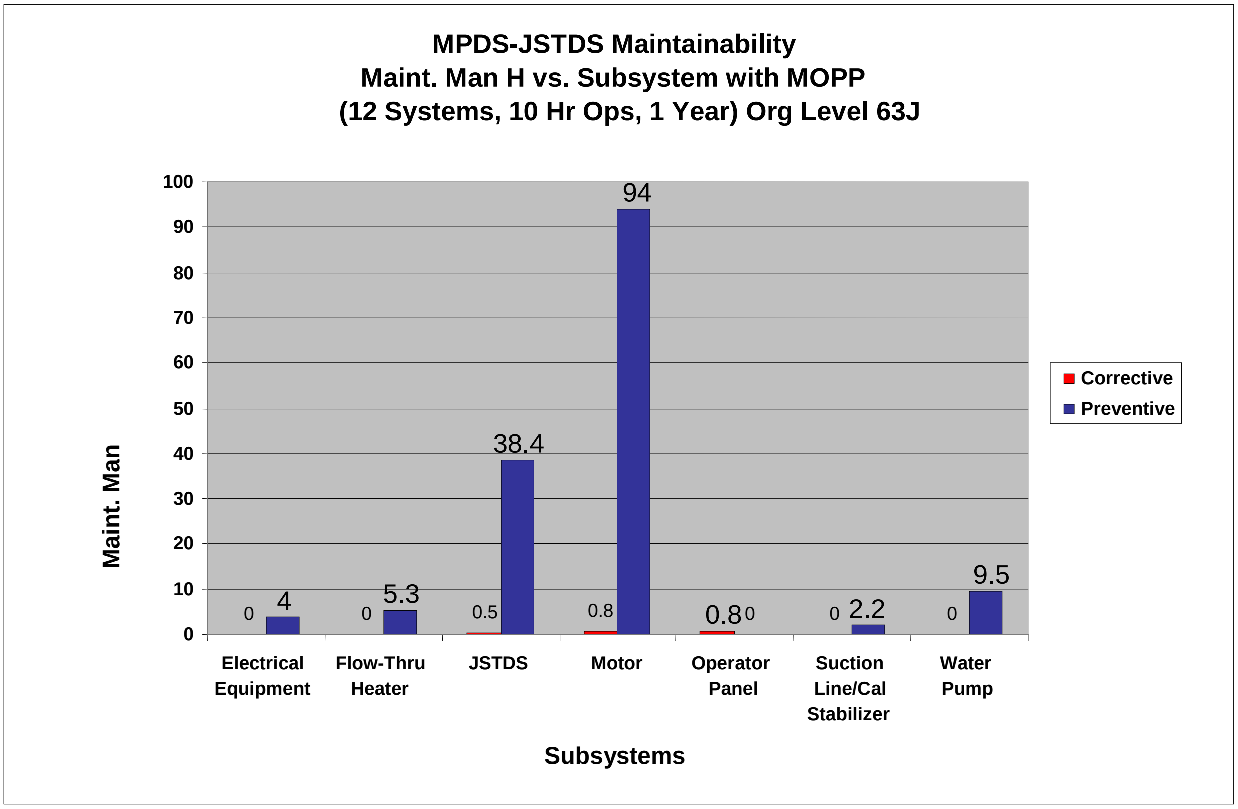

Figure 14. JSTDS-SS Increment I maintenance hours with MOPP.

All MMH values increased roughly by a factor of 2. Since this is a worst-case scenario, the rest of the figures are based on this condition. As in figure 13, the subsystems with the highest number of preventive MMH are the motor and JSDTS. A small number of corrective MMH are shown for the JSTDS, motor, and operator panel subsystems. The following figures show the breakdown of the subsystems into their respective components. Figure 18, for example, depicts the high driver components that compose the 94 MMH for the motor. It shows that valve adjustments and oil changes are two of the tasks requiring the most maintenance time.

Figure 15 shows only one component under the electrical subsystem; however, this is the nomenclature in the operation and maintenance manual used to describe the cleaning and checking of all electrical equipment after every 500 h of operation. It was included as part of the figures describing the breakdown of component MMH.

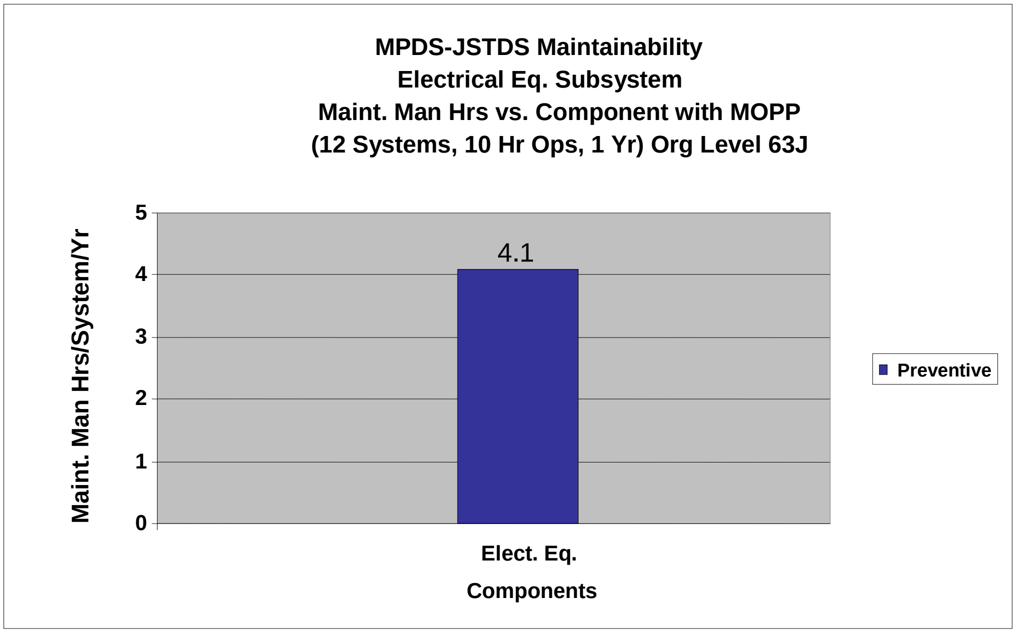

Figure 15. JSTDS-SS Increment I electrical subsystem.

Figure 16 shows only one component that composes the flow-through heater subsystem. Although the operation and maintenance manual listed the three components separately, an SME suggested that the three be combined into one component task, as shown in the figure.

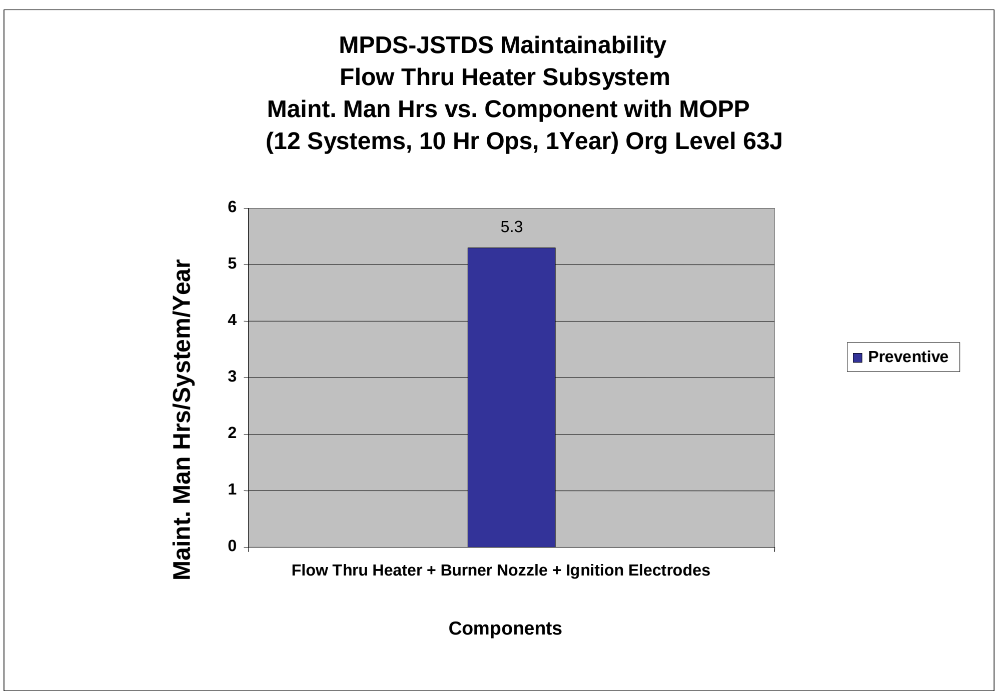

Figure 16. JSTDS-SS Increment I flow-through heater subsystem.

Figure 17 illustrates the components that compose the JSTDS subsystem. As was pointed out earlier, note the disparity between the preventive and corrective MMH. This subsystem and the motor subsystem, which is described in the next figure, are the two largest users of MMH.

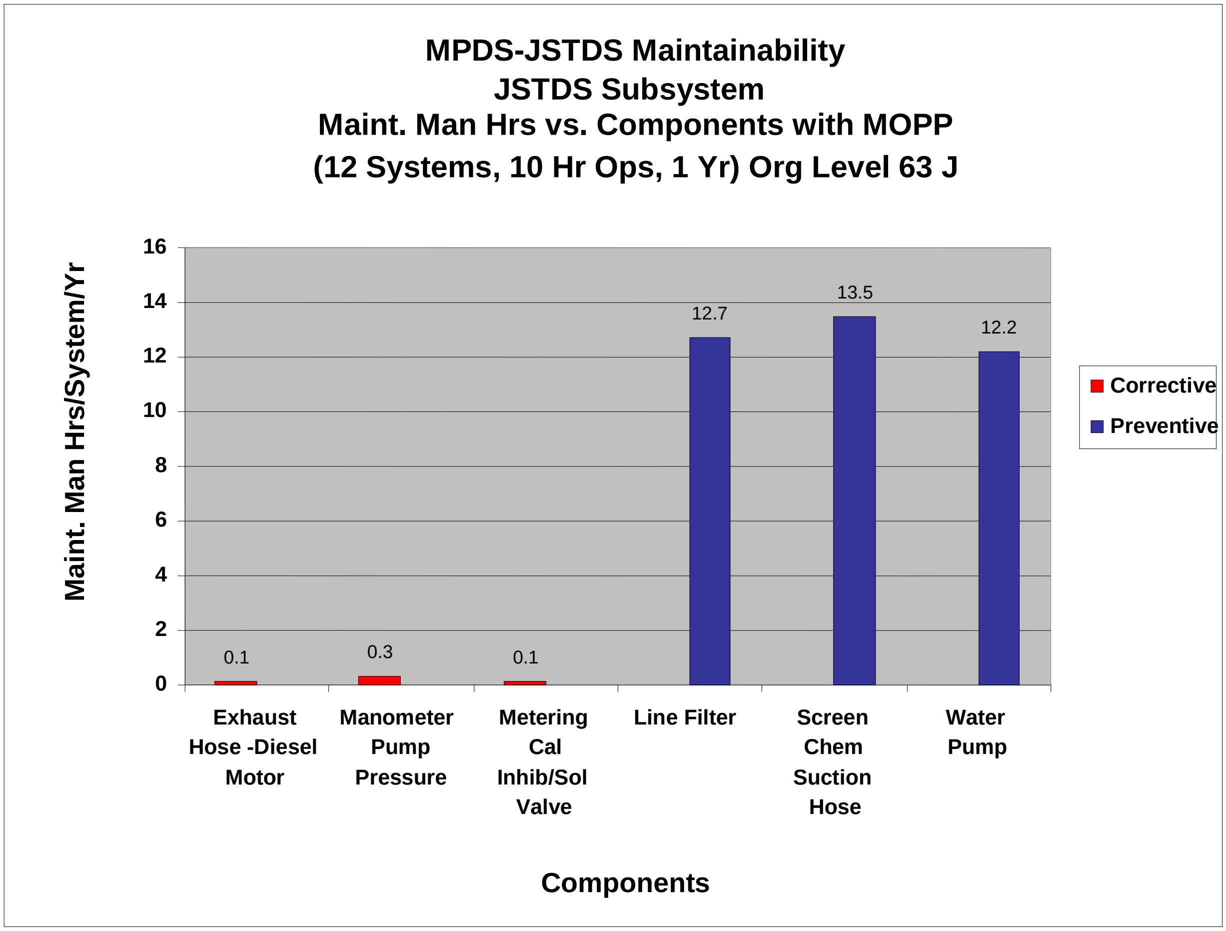

Figure 17. JSTDS-SS Increment I components.

Figure 18 describes the motor subsystem, which represents a total of 94 MMH for preventive maintenance and is the subsystem that requires the most MMH. It is evident that the high driver tasks within these components are the following: adjust the valves, change the oil, check all attachment bolts, and clean the cooling fins. Very little corrective maintenance is required.

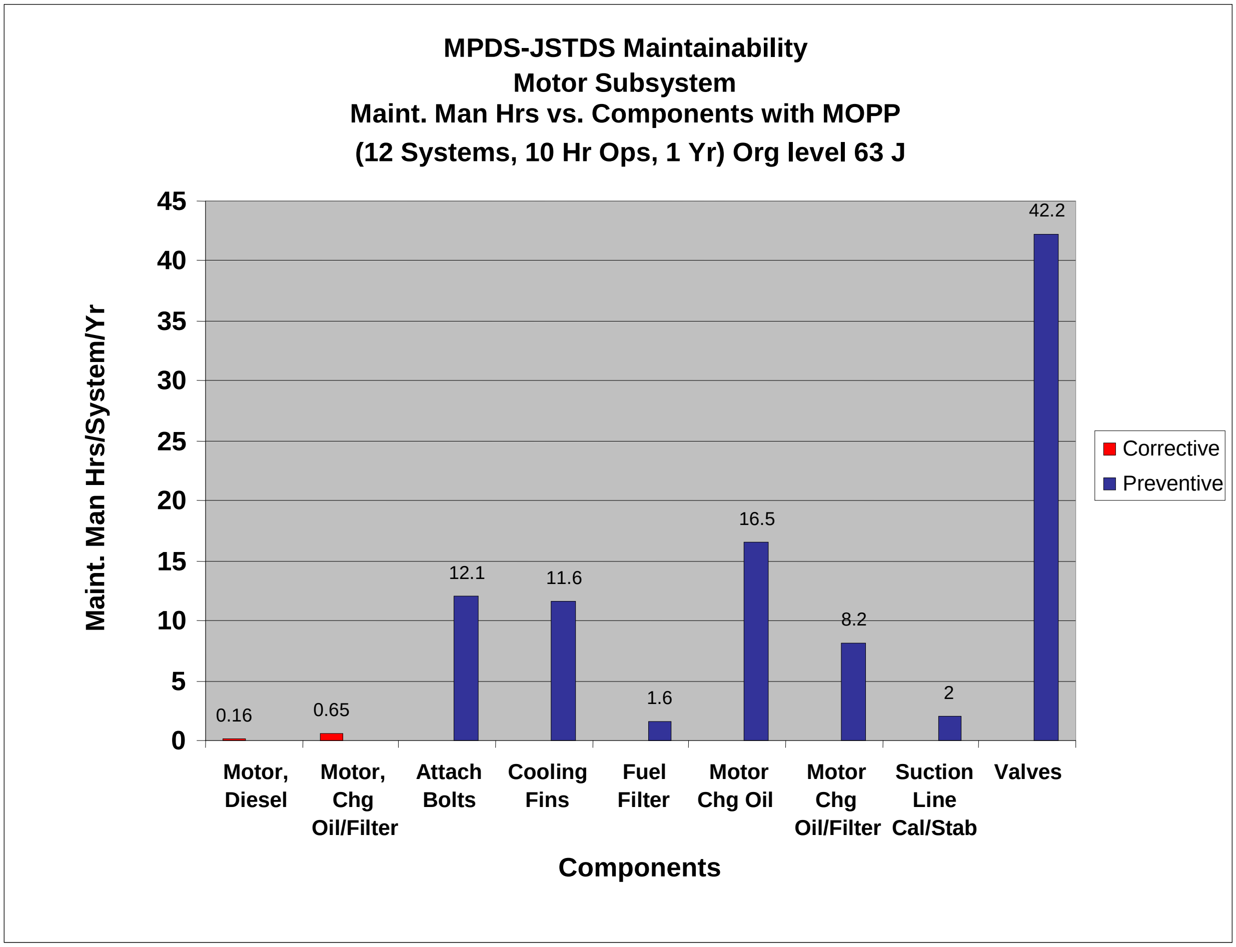

Figure 18. JSTDS-SS Increment I motor subsystem.

Figure 19 illustrates the only subsystem (operator panel) with no preventive maintenance. Therefore, only corrective maintenance components are graphed. These represent very low maintenance numbers. For instance, the total time represented is 0.83 h, or ~50 min of corrective maintenance per system per year for the operator panel. This total, combined with the other very low number of corrective maintenance hours for the other subsystems, results in a main system that requires very little corrective maintenance overall.

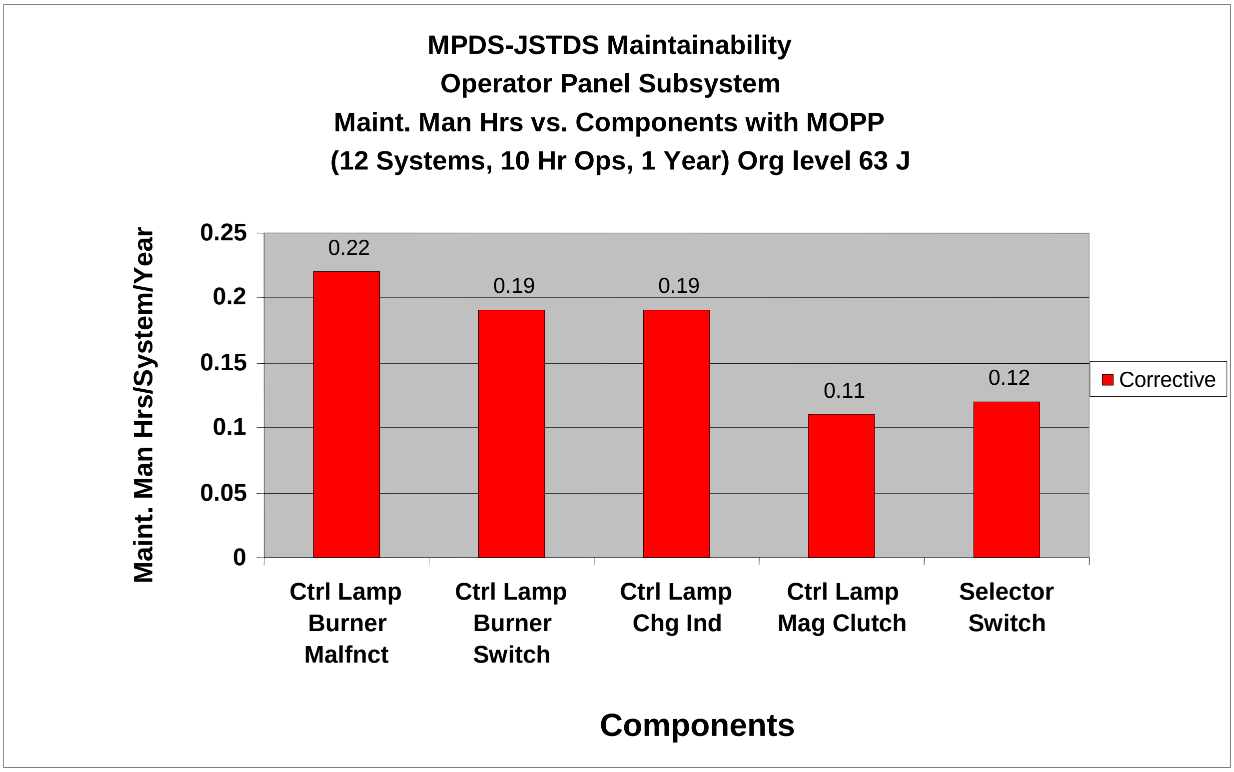

Figure 19. JSTDS-SS Increment I operator panel subsystem.

Figure 20 illustrates the one component described in the operation and maintenance manual that composes the preventive MMH required in the suction line/calcium stabilizer subsystem for a total value of 2.2 MMH.

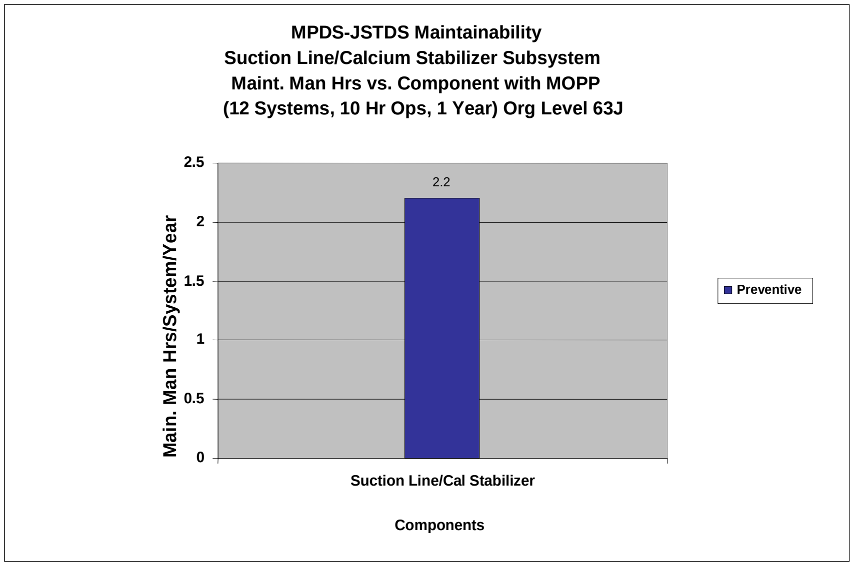

Figure 20. JSTDS-SS Increment I suction line/calcium stabilizer subsystem.

Figure 21 illustrates the three components that make up the water pump subsystem. These include the pulsation damper, valves, and water pump housing. The aggregate value of preventive maintenance for these components is 9.5 MMH/system/year.

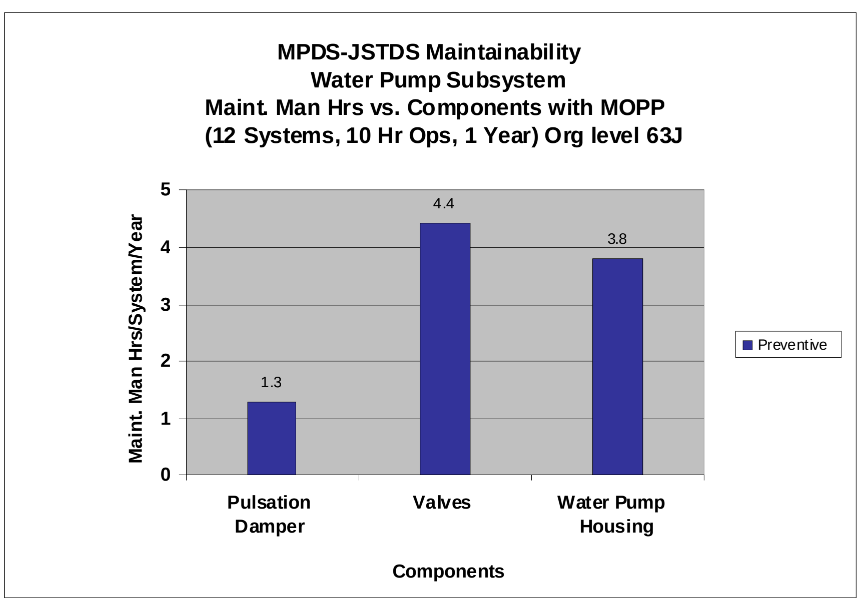

Figure 21. JSTDS-SS Increment I water pump subsystem.

Figure 22 illustrates the total values for both corrective and preventive MMH per system per year. The preventive MMH values are far greater than the corrective MMH values due to reasons cited earlier (i.e., the majority of the corrective MOUBFs exceeded the model simulation time of 1 year of operational hours). The combined total of corrective and preventive maintenance is 157 h, which is about 4 weeks (40 h/week) of maintenance for a system operating 10 h/day, 7 days/week for 1 year. This yields a value of 0.04 for the average maintenance per operating hour per system, which seems very reasonable. In fact, it suggests that one 63J operator/maintainer could maintain more than one system, assuming any maintenance requirements for the different systems did not occur simultaneously. This could result in significant manpower and cost savings.

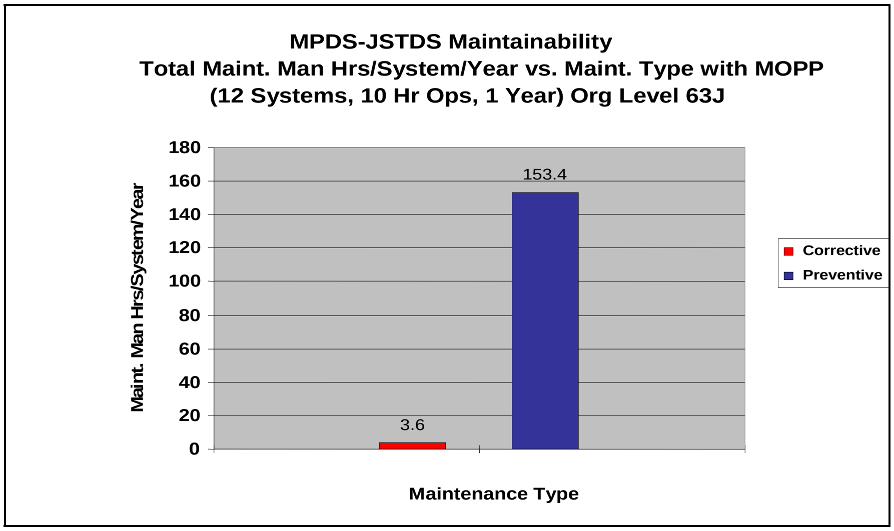

Figure 22. JSTDS-SS Increment I total values for corrective and preventive MMH hours per system annually.

As a final note, the corrective maintenance value of 3.6 h seems very low. Additional maintenance studies should examine component failures from additional EDTs and field usage.

4.3 Human Factors Engineering Assessment

The following issues were identified as needing further investigation:

- potential to exceed weight-lifting limits,
- high heat exposure,
- high-level noise emission,
- communication restriction due to noise, and
- non-standardized labeling.

These issues were individually addressed through appropriate analyses.

4.3.1 Weight Limit Guidelines

The JSTDS-SS Increment I applicator module weighs ~562 lb. The JSTDS-SS Increment I has eight handles and an integral opening in the frame to accommodate military and industrial forklift tines. The 562-lb weight of the JSTDS-SS Increment I exceeds the MIL-STD-1472F maximum lifting and/or carrying limits for an eight-person, mixed-gender team for each condition. For a male-only team, the JSTDS-SS Increment I exceeds the MIL-STD-1472F maximum lifting and/or carrying limits for all conditions except for condition B (see table 9) (*11*). With eight handles, an all-male, eight-person crew can only carry 533 lb, lift 566 lb to a surface not greater than 3 ft above the floor, and lift 364 lb to a surface not greater than 5 ft above the floor.

Table 9. MIL-STD-1472F maximum design weight limits (*11*).

Condition	Population Male and Female	Population Male Only
Lift an object from the floor and place it on a surface not greater than 5 ft above the floor.	16.8 kg (37 lb)	25.4 kg (56 lb)
Lift an object from the floor and place it on a surface not greater than 3 ft above the floor.	20.0 kg (44 lb)	39.5 kg (87 lb)
Carry an object 33 ft or less.	19.0 kg (42 lb)	37.2 kg (82 lb)

4.3.2 Heat Stress Model

Technical Bulletin (TB) MED 507 (*12*) describes maximal exposure limits for wet bulb globe temperatures without impairing mental performance. MOPP gear is required for use by the operator of the JSTDS-SS Increment I during normal decontamination operations and increases the environmental stressor by raising the body core temperature by an additional 10 °F. This additional stressor may occur while operating the JSTDS-SS Increment I for extended durations.

Using guidance from ARL-MR-346 (*8*), the analysis of heat stress is drawn from factoring in multiple variables, including temperature, exposure time, and workload level. Assuming the worst-case scenario using an operating condition of 100% humidity, 85 °F, and high workload condition, the following was determined:

- Maximum work time allotted is 38.6 min.
- Probability of casualties is 100%.

Using mission completion time data from IMPRINT modeling, the shortest mission (by two scouts without MOPP gear) was completed in a time of 38 min and 32 s (see table 10), which was longer than the maximum work time allotted for high heat, humidity, and workload conditions.

Table 10. Mission completion times.

Mission Completion Time (hh:mm:ss:ms)[a]			
Single Scout Without MOPP	**Single Scout With MOPP**	**Dual Scout Without MOPP**	**Dual Scout With MOPP**
01:17:33	02:04:26:07	00:38:32:40	01:01:25:32

[a] hours:minutes:seconds:milliseconds.

4.3.3 Noise Level Study

Acoustic energy (steady-state noise) levels may exceed 85 dBA during JSTDS-SS operation. The potential sources of steady-state noise associated with the JSTDS-SS Increment I are the applicator module (e.g., water pump, heater, engine, and blower) and the spray wand. Noise reduction mufflers reduced the acoustic noise produced by the applicator module to <91 dBA. Depending on operating conditions, the noise levels at the Warfighter's ears may be in excess of the 85-dBA level, even when they are located several feet from the applicator module. This issue was identified by the U.S. Army Center for Health Promotion and Preventive Medicine (CHPPM) and included in the updated Health Hazard Assessment Report (HHAR) (*13*).

4.4 Soldier Survivability Assessment

4.4.1 Communication Restriction

Due to high noise levels during system operation and the requirement of hearing protection of personnel within 50 ft of an operating JSTDS-SS Increment I applicator module, communication is restricted between personnel. This can potentially cause errors and damage to equipment.

4.4.2 Labeling Standards

Symbols on the operator control panel are not universal symbols, not easily understood, and may not be visible under all anticipated lighting conditions during decontamination operations, potentially causing operator error, damaging equipment and jeopardizing mission safety and effectiveness.

5. Results

5.1 Combined MANPRINT Assessment

The combined HFEA, SSvA, and MPTA assessment identified no critical issues, one major issue, and four minor issues across three domains for the JSTDS-SS Increment I. Based on a review of the available individual domain assessments, the overall MANPRINT rating of the JSTDS-SS Increment I was Amber. There were no known issues that will prevent the JSTDS-SS from transitioning to milestone C, full-rate production, material release, and type classification decision. However, the following major and minor issues identified in each domain should be resolved as soon as possible during the next acquisition phase:

5.1.1 Major Issue

1. HFE: JSTDS-SS Increment I exceeds eight-man lift weight limit guidelines (*11*), as shown in table 9.

   - Operational Impact: The Army should expect personnel to injure themselves when lifting the JSTDS-SS Increment I applicator module without the use of mechanical lift.

   - Recommendation: Do not permit personnel to move, carry, or lift the JSTDS-SS Increment I manually, as stated in the HHAR (*13*). The JSTDS-SS Increment I has been marked prominently indicating lift or carry only by mechanical device.

5.1.2 Minor Issues

1. HFE: Acoustic energy (steady-state noise) levels may exceed 85 dBA.

   - Operational Impact: Soldiers may experience hearing damage while using this equipment.

   - Recommendation: Require all personnel within ~30 ft of an operating JSTDS-SS Increment I applicator module to wear properly fitted, DOD-approved combat earplugs or hearing protection devices in accordance with MIL-STD-1474D (*14*). The JSTDS-SS applicator module has warning labels affixed to the system that state that all personnel within 50 ft of the system are required to wear hearing protection. However, current labels do not conform to accident prevention tags (see 29 CFR 1910.145 [*15*]). Additional warnings and labels are also identified in the user and maintenance manuals, as well as outlined in the JSTDS-SS training support plan.

2. HFE/SSv: Users may experience communication restriction.

  - Operational Impact: Soldiers face a potential increase in errors and damage to equipment.

  - Recommendation: The program manager should consider a two-way bone conduction microphone and speaker communication device that has a high noise tolerance and provides freedom to both ears. This device will attach directly to the protective mask head strap and provide an alternative to the use of hand and arm signals during operations under normal conditions and limited visibility.

3. HFE: Symbols on the operator control panel are not universal symbols, not easily understood, and should be visible under all anticipated lighting conditions during decontamination operations.

  - Operational Impact: There is a possibility of operator errors, damage to equipment, and mission failure due to poor visibility of warning labels or placards under all anticipated lighting conditions.

  - Recommendation: The operator should be able to control and monitor all parameters (e.g., spray pressure and temperature) to effectively use the system and select the application method. Adjustable illumination shall be provided for visual displays (including display, control, and panel labels and critical markings) that must be readable under darkened conditions in accordance with MIL-STD-1472F (*11*). Change the warning label symbols on the control panel to be more intuitive or universal and ensure visibility during day and night decontamination operations.

4. HFE: Operator heat stress may occur while operating the JSTDS-SS Increment I for long duration in warm climates.

  - Operational Impact: According to the Operational Mode Summary/Mission Profile, the JSTDS-SS Increment I will operate in hot climates 15% of the time in a wartime scenario and 25% of the time in peacetime. Excessive heat stress during decontamination operation will cause accelerated fatigue, possibly increasing the probability of errors, and could cause heat casualties for personnel operating the system in hot climates. These factors will reduce the ability of the JSTDS-SS Increment I to perform its mission in hot climates.

  - Recommendation: Implementation of preventive measures to reduce heat stress factors, as described in TB MED 507 (*12*), ARL-MR-346 (*8*), or FM 3-11.5 (*5*), is required to preclude serious injury or death of operators in MOPP ensemble. Maintain close observation of JSTDS-SS Increment I operators for early signs and symptoms of heat stress, ensure adequate water replacement, and monitor work-rest cycle during decontamination operations.

5. HFE/MPTA: The mission completion times are shown in table 11. Results for IMPRINT operator modeling revealed the MOPP ensemble has a time-degradation effect on the performance of the operators and increases the mission completion time by 46 min for the single-operator condition and by 23 min in the dual-operator condition.

- Operational Impact: Mission completion times are predicted to be longer due to the operator wearing the MOPP, thereby increasing heat stress exposure and reducing operator performance.

- Recommendation: There is no instance of overload among any conditions, either single or dual operator. The highest workload value (15.4) occurs when verifying the vehicle stability before the spray-washing process begins. In an operational environment, the goal is to conduct decontamination as safely and quickly as possible to minimize exposure to hazardous substances. The mission can be completed with one operator, although mission completion time could be further decreased with an additional operator if necessary, also minimizing heat stress exposure. Stressor conditions, however, increase mission completion times regardless of the number of operators.

Table 11. Comparison of single and dual operators' overall average workload and mission completion times.

<table>
<tr><th colspan="6">Mission Completion Time (hh:mm:ss:ms)[a]</th></tr>
<tr><th colspan="2">Single Operator</th><th colspan="4">Dual Operator</th></tr>
<tr><td>MOPP</td><td>No MOPP</td><td colspan="2">MOPP</td><td colspan="2">No MOPP</td></tr>
<tr><td>—</td><td>—</td><td>Op 1</td><td>Op 2</td><td>Op 1</td><td>Op 2</td></tr>
<tr><td>02:04:26:07</td><td>01:17:33:00</td><td colspan="2">01:01:25:32</td><td colspan="2">00:38:32.40</td></tr>
</table>

[a] hours:minutes:seconds:milliseconds.

6. Summary

The overall rating of the JSTDS-SS Increment I system was Amber. No critical issues, one major issue, and four minor issues were identified. Based on available information on the JSTDS-SS Increment I derived from a fielded system, each of the combined assessment domains rating is summarized as follows:

1. Manpower, personnel, and training rating: Green. The combined HFE, MPT, and SSvA assessment was prepared by the ARL Human Research and Engineering Directorate (ARL/HRED). The MPTA identified no critical issues, no MPT major issues, and no MPT minor issue for the JSTDS-SS.

2. Human factors engineering rating: Amber. The combined HFE, MPT, and SSvA assessment was prepared by ARL/HRED. The HFE assessment identified no critical issues, one major issue, and four minor issues for the JSTDS-SS Increment I.

3. System safety rating: Green. A Programmatic Environment, Safety and Occupational Health Evaluation (PESHE) was prepared for the JSTDS-SS. The PESHE confirmation states that the JSTDS-SS Increment I is considered safe for Soldier operation, maintenance, and transportation.

4. Health hazards rating: Amber. An HHAR was prepared for the JSTDS-SS (*13*) by CHPPM. CHPPM identified one high-risk hazard, four medium risk hazards (chemical substances and engine combustion products; acoustic energy: steady-state noise [engine/pump assembly]; musculoskeletal trauma: lifting and moving engine/pump assembly; and temperature extremes: heat injuries and spray wand operation), and two low-risk hazards that are chemical substances (fuels and non-fuel petroleum oils, lubricants, and coolant) associated with the JSTDS-SS. The one high-risk and five medium-risk items were presented in the HFE section. The two low-risk items contained in the HHAR have been forwarded to the program manager for mitigation.

5. Soldier survivability rating: Green. The combined HFE, MPT, and SSvA assessment was prepared by ARL/HRED (*16*). HRED recommends that the program transition to the next acquisition phase. The SSvA identified no critical, major, or minor issues for the JSTDS-SS Increment I.

It is recommended that the JSTDS-SS Increment I transition to full-rate production (FRP), material release, and type classification standard. Based on the acquisition approach and data sources available, there are no issues or groups of issues that preclude transitioning to the next phase of the material acquisition life cycle. However, the issues that were identified require resolution before JSTDS-SS Increment I FRP. In addition, any issues identified in the safety assessment report also require resolution prior to the JSTDS-SS Increment I FRP decision.

7. References

1. AR 602-2. *Manpower and Personnel Integration (MANPRINT) in the System Acquisition Process* **2001**.

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5. FM 3-11.5. *Multiservice Tactics, Techniques, and Procedures for Chemical, Biological, Radiological, and Nuclear Decontamination*; U.S. Army Training and Doctrine Command: Fort Monroe, VA **2006**.

6. Engineered Air Systems, Inc. Combined Manpower, Personnel, and Training Assessment Human Factors Engineering Workload Assessment for the JSTDS-SS, JSTDS-SS Environmental, Safety and Occupational Health Assessment Report.

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8. Tauson, R. A.; Doss, N. W. *Effects of Temperature and Humidity on Squad Performance in the Proposed U.S. Marine Corps Advanced Assault Amphibious Vehicle*; ARL-MR-346; U.S. Army Research Laboratory: Aberdeen Proving Ground, MD, 1997.

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10. U.S. Department of the Army. Final report for the Engineering Design Testing (EDT) of the JSTDS-SS; January 2006.

11. MIL-STD-1472F. *Human Engineering* **1999**.

12. U.S. Department of the Army and Air Force. *Heat Stress Control and Heat Casualty Management*; TB MED 507; Headquarters, Washington, DC, 2003.

13. U.S. Department of the Army. Health Hazard Assessment Report of the Joint Service Transportable Decontamination System-Small Scale, Project No. 69-MP-OAGD-09; November 2008.

14. MIL-STD-1474D. *Noise Limits* **1997**.

15. 29 CFR 1910.145. Specifications for Accident Prevention Signs and Tags. *Occupational Safety and Health Standards* **1996.**

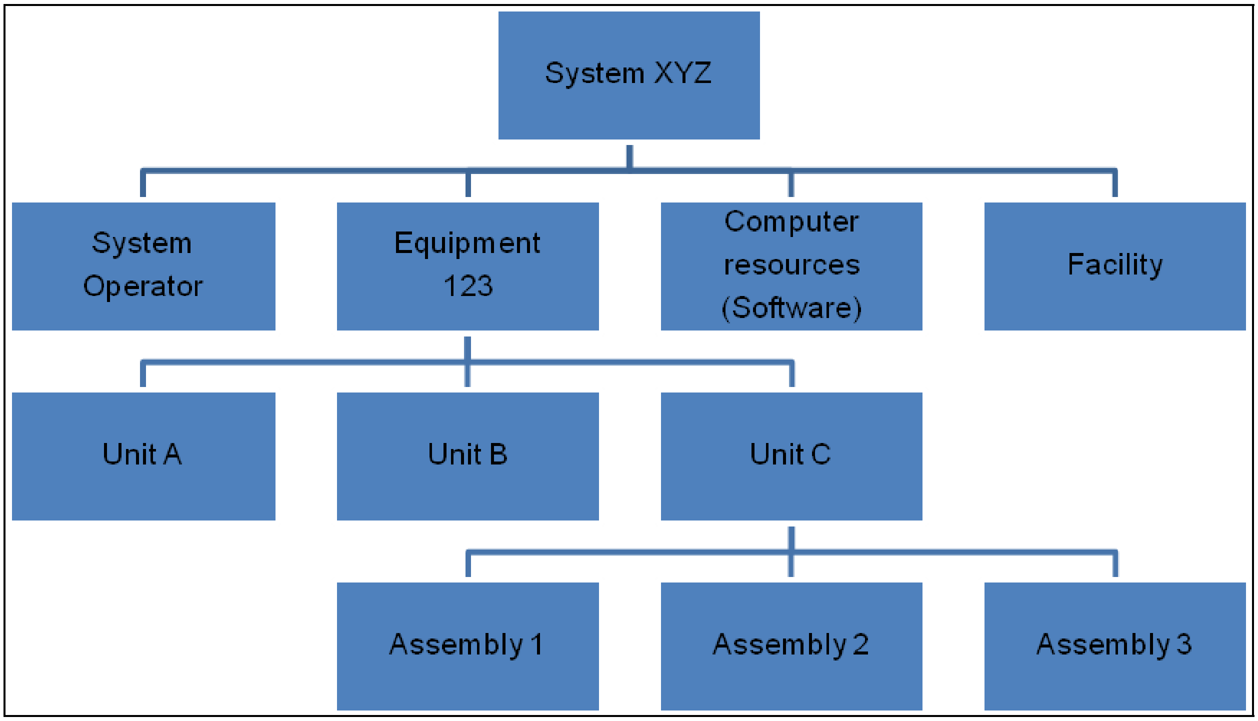
16. U.S. Army Research Laboratory. Amendment to the Addendum to Combined Human Factors Engineering Assessment (HFEA), MANPOWER, Personnel, Training Assessment, and the Soldier Survivability Assessment for the Joint Service Transportable Decontamination System – Small Scale (JSTDS-SS) Increment I Full-Rate Production, Material Release; Aberdeen Proving Ground, MD, May 2009.

Appendix A. IMPRINT Maintenance Model Acronym List

CBRN	Chemical Biological, Radiological, and Nuclear
EDT	Engineering Design Testing
HE	Human Engineering
HFEA	Human Factors Engineering Assessment
HHAR	Health Hazard Assessment Report
IMPRINT	Improved Performance Research Integration Tool
JBPDS	Joint Biological Point Detection System
JPM Decon	Joint Project Manager for Decontamination
JSTDS SS	Joint Service Transportable Decontamination System – Small Scale
MANPRINT	Manpower and Personnel Integration
MDR	Milestone Decision Review
MMH	Maintenance Man Hours
MOPP	Mission-Oriented Protective Posture
MOS	Military Occupation Specialty
MOUBF	Mean Operational Units Between Failure
MOUBM	Mean Operational Units Between Maintenance
MPDS JSTDS	Multi-Purpose Decontamination System – Joint Service Transportable Decontamination System
MPT	Manpower, Personnel, and Training
MPTA	Manpower, Personnel, and Training Assessment
MTBF	Mean Time Between Failure
MTTR	Mean Time to Repair
ORD	Operational Requirements Documents
POC	Point of Contact
RAM	Reliability, Availability, and Maintainability
SME	Subject Matter Expert
SSvA	Soldier Survivability Assessment
TM	Technical Manual

Appendix B. Functional Breakdown of a System to Subsystems and Components

This appendix appears in its original form, without editorial change.


System XYZ
System Operator
Equipment 123
Computer resources (Software)
Facility
Unit A
Unit B
Unit C
Assembly 1
Assembly 2
Assembly 3

Appendix C. Negative Exponential Distribution and Series Reliability Equations

C.1 Reliability Function (Survival Function)

$$R(t) = \int_t^\infty \frac{1}{\theta} e^{-t/\theta} dt = e^{-t/\theta} \quad . \tag{B-1}$$

Mean life (θ) is the arithmetic average of the lifetimes of all items considered, which for the exponential function is mean time between failure (MTBF), and t is the time period of interest.

$$R(t) = e^{-t/M} = e^{-\lambda t} \quad , \tag{B-2}$$

where λ is the failure rate (or corrective maintenance frequency) and M is the MTBF.

$\lambda = 1/\theta = 1/\text{MTBF}$ (for the exponential distribution).

C.2 Series Reliability

$$R_S = (e^{-\lambda_1 t})(e^{-\lambda_2 t})....(e^{-\lambda_n t}) \quad . \tag{B-3}$$

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